Correlated Processes in the Inner-Shell Photodetachment of the Na^- Ion

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Photodetachment studies of negative ions have, until recently, involved the valence electrons only. Double excitation, a clear sign of the importance of electron correlation, has been investigated extensively during the past few decades[1]. Such measurements used lasers as the source of UV photons. At much higher levels of excitation, one can expect to observe thresholds and resonances in the photodetachment cross section arising from the detachment and/or excitation of an inner-shell electron. To reach these high levels of excitation, which in the present case lie in the XUV region, it is necessary to replace lasers with a synchrotron radiation source. The present experiment was performed on the photon-ion endstation 10.0.1.2 at the 10.0.1 beamline at the Advanced Light Source.

In the experiment we collinearly overlapped a beam of Na^- ions from a low-energy accelerator with a beam of XUV photons from the ALS. Na^- ions were produced in a sputter ion source, extracted at an energy of 5 keV and focused using a series of cylindrical electrostatic lenses. The ion beam was momentum-selected using a 60^o analyzing magnet. The cross sectional area of the ion beam was defined by two sets of adjustable slits. After momentum-selection and collimation, the ion beam was merged onto the axis of a counter-propagating photon beam using a set of 90^o spherical-sector bending plates. The primary beam then entered a 29.4 cm long cylindrical interaction region which was biased at +2 kV to energy label the Na^+ ions produced as a result of the photon-ion interactions. The energy labeling of these photo-ions enabled us to distinguish them from the Na^+ ions produced in double detachment collisions of the Na^- ions with the residual gas along the unbiased region of the ion beam line. This background contribution was also reduced by maintaining a vacuum of $5x10^{-10}$ Torr in the beam line. After the interaction region, a 45^o analyzing magnet was used to separate the energy-labeled Na^+ ions produced in the biased interaction region from the primary Na^- ion beam. These ions had an energy of 9 keV, whereas most of the collisionally detached background ions had an energy of 5 keV, as determined by the extraction voltage at the ion source. Typical Na^- ion currents in the interaction region were 1-6 nA. The magnitudes of the ion current and photon intensity were monitored for normalization purposes. The photon beam was modulated at 1 Hz in order to discriminate against the collisionally-induced background of 9 keV Na^+ ions produced in the interaction region. The Na^+ photo-ions were further deflected, in the vertical dispersion plane, by the use of a set of 90^o spherical-sector bending plates. This was to minimize any background arising from the collection of the Na^- primary beam. The dispersed Na^+ photo-ions then entered a negatively-biased detection box, where the ions impinged on a metal plate and produced secondary electrons. These secondary electrons were, in turn, accelerated toward a microchannel plate detector. The processed pulses from this detector were counted with a multi-function I/O board in a PC-based data acquisition and control system. The Na^+ signal, which is proportional to the cross section, is shown, as a function of photon energy, in Figure 1. This figure is made up of two data sets taken under different conditions and smoothed separately. In the range 30-40 eV, the resolution and step size were 40 meV and 6 meV, respectively. In the range 40-51 eV the resolution and step size were both 100 meV. Further details can be found in a recent publication [2].

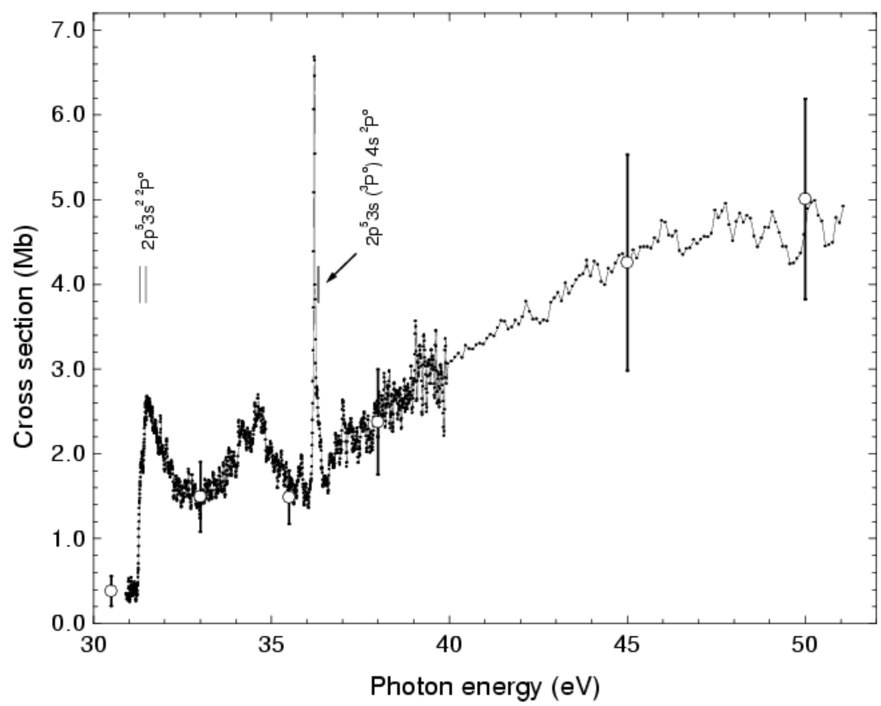

Figure 1 Total cross section for photodetachment of Na^- over energy range 30-51 eV. The six measurements represented by open circles were used to establish the cross-section scale. The scale shown is a lower limit. Thresholds are indicated by vertical lines.

Figure 1 shows the photodetachment cross section of the Na^- ion leading to the production of the Na^+ ion. In the measured energy range 30-51 eV, two distinct processes contribute to the cross section. There is the non-resonant process involving the direct photodetachment of a 2p electron from Na^- producing Na atoms in core-excited states, which rapidly decay via Auger emission to form Na^+ ions. The first channel to open is the $Na(2p^5 3s^2)^2P^o + e^-$ channel. The fine structure channels associated with the $^2P^o$ levels can be clearly seen. The sharp opening of this channel is expected for dominant s-wave emission. This channel is the most prominent non-resonant channel over the energy range studied. The cross rises gradually from threshold to a maximum slightly beyond the range of our measurements. At higher energies, detachment of the 2p electron is often accompanied by the excitation of a valence electron. Resonant processes are also apparent in the cross section. The resonances arise from photoexcitation of core-excited states of the Na^- ion of $^1P^o$ symmetry, which subsequently decay via autodetachment to corresponding core-excited states of the Na atom. The excited Na atoms then decay via the Auger process to produce Na^+ ions. The probability of radiative decay to the bound states should be very small. The most prominent feature of the cross section in the range studied is the Na^- resonance at 36.213 eV. This narrow peak lies very close to the threshold for the opening of the $Na(2p^5 3s(^3P^o)4s)^2P^o + e^-$ channel. It is most likely associated with the autodetaching decay of a core-excited $^1P^o$ state of Na^- with a major configuration of the type $2p^5 3s4snl$, where l is even. The resonance appears to be just below the parent threshold. Feshbach resonances, such as this, are known to narrow as they approach their parent threshold. The strength of the prominent Na^- resonance, in comparison to corresponding resonances in Na, clearly demonstrates the much higher degree of correlation associated with double excitation process in the negative ion than in the atom. Other, weaker resonances, have been observed in the cross section. Details can be found in reference [2].

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References

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